

The 3D structure of turbulent channels up to $\text{Re}_\tau = 4000$

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Abstract

Several time-resolved fluid dynamics videos of turbulent channels from $\text{Re}_\tau = 180$ to $\text{Re}_\tau = 4000$ are presented. The videos show the temporal evolution of sweeps (bluish) and ejections (reddish) in one half of the channel (only the bottom wall is shown). The color changes from dark for points close to the wall, to bright for those reaching the center of the channel. As the Reynolds number increases the scale separation becomes more clear and the complexity of the dynamics observed rises.

1 Introduction

The efforts to describe wall-bounded turbulent flows in terms of coherent motions date at least to the experiments in [1]. These structures have played an important role in the understanding of turbulence organization and its dynamics. Data from Direct Numerical Simulations allows us to study the properties of these objects in three dimensions for different snapshots, but their dynamics can not be completely solved without tracking them in time. That temporal evolution has already been studied for either very small or large structures at moderate Reynolds numbers but a temporal analysis of 3D structures spanning from the smallest to the largest scales across the logarithmic layer has not been performed yet. Some attempts have been done [3], although in very small domains and at moderate Reynolds numbers. In the present video, 3D sweeps and ejections are plotted using turbulent channels datasets performed in a physical domain big enough to not influence the largest structures in the logarithmic region (for the highest Reynolds

numbers) and small enough to obtain a reasonable and tractable amount of data. The highest Reynolds number ensures the presence of a wide range of scales and a healthy logarithmic region, that would allow us to study the dynamics of the coherent structures in time.

2 Results shown in the video

The flow is moving on average in the streamwise direction x , z is the spanwise direction and y the wall-normal one. The superindex $+$ denotes wall units and the wall is located at $y^+ = 0$. The domain size in all the cases is $L_x = 2\pi h$, $L_z = \pi h$ and $L_y = 2h$ where h is the channel half height. The incompressible flow is integrated in the form of evolution equations for the wall-normal vorticity and for the Laplacian of the wall-normal velocity, as in [2], and the spatial discretization is dealiased Fourier in the two wall-parallel directions. Reynolds numbers $Re_\tau = 180$ and 950 use Chebychev polynomials in y whereas $Re_\tau = 2000$ and 4000 use seven-point compact finite differences. Time stepping is the third-order semi-implicit Runge-Kutta in [6].

The coherent structures represented are characterized in [4]. They are the structures contributing most to the Reynolds stresses and are obtained by extending the one-dimensional quadrant analysis of [5] to three dimensions. They are connected regions satisfying

$$\tau(\mathbf{x}) > Hu'(y)v'(y), \quad (1)$$

where $\tau(\mathbf{x}) = -u(\mathbf{x})v(\mathbf{x})$ is the instantaneous point-wise tangential Reynolds stress with u and v are the velocity fluctuations in streamwise and wall-normal directions respectively. H is the hyperbolic-hole size and it is set to 1.75 in all the cases. An object is classified as belonging to the different quadrants according to the signs of the mean u and v .

Only structures belonging to quadrants 2 (ejections) and 4 (sweeps) are plotted. The sweeps are colored in blue and ejections in red in one half of the channel. Their color changes from dark for points close to the wall, to bright for those reaching the center of the channel.

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References

- [1] H. T. Kim, S. J. Kline, and W. C. Reynolds. The production of turbulence near a smooth wall in a turbulent boundary layer. *J. Fluid Mech.*, 50:133–160, 1971.
- [2] John Kim, Parviz Moin, and Robert D Moser. Turbulence statistics in fully developed channel flow at low Reynolds number. *J Fluid Mech*, 177:133–166, 1987.
- [3] A Lozano-Durán and J. Jiménez. Time-resolved evolution of the wall-bounded vorticity cascade. *63rd Annual Meeting of the APS Division of Fluid Dynamics*, 2011.
- [4] A. Lozano-Durán and J. Jiménez. The three dimensional structure of momentum transfer in turbulent channels. *J. Fluid Mech.*, 694:100–130, 2012.
- [5] S S Lu and W W Willmarth. Measurements of the structure of the Reynolds stress in a turbulent boundary layer. *J Fluid Mech*, 60:481–511, 1973.
- [6] P. R. Spalart, R. D. Moser, and M. M. Rogers. Spectral method for the Navier–Stokes equations with one infinite and two periodic dimensions. *J. Comput. Phys.*, 96:297–324, 1991.